

UNITED STATES PATENT APPLICATION

For

SILOXIRANE BASED NO-FLOW UNDERFILL MATERIAL

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# SILOXIRANE BASED NO-FLOW UNDERFILL MATERIAL

## BACKGROUND OF THE INVENTION

### 1). Field of the Invention

[0001] This invention relates to a no-flow underfill material.

### 2). Discussion of Related Art

[0002] A semiconductor package may be constructed from a package substrate having bond pads thereon and an integrated circuit die having bumps formed thereon. A fluxing agent is usually deposited over the package substrate and the bond pads and the bumps are then brought into contact with the bond pads. Subsequent heating in a reflow oven attaches the bumps to the bond pads. The fluxing agent removes oxides from surfaces of the bond pads and bumps to ensure a reliable joint between the bumps and the bond pads.

[0003] The fluxing agent is subsequently washed out in a defluxing machine. An underfill material is then dispensed next to the die on the substrate utilizing a dispensing machine. The underfill material then flows under capillary action into and fills a gap between the die and the substrate, with or without the help of heating. The underfill material serves to redistribute stresses on the bumps due to a mismatch in a

coefficient of thermal expansion (CTE) of the substrate and a CTE of the die when the package is heated or cooled.

[0004] A so-called no-flow underfill material may be used instead of a conventional fluxing agent to eliminate the need for a defluxing machine and other machinery, and to significantly reduce throughput time. A no-flow underfill material is applied like a conventional fluxing agent and to an extent serves the purpose of a conventional fluxing agent. The no-flow underfill material cures while the package is transferred through a reflow oven, and, to an extent, can then serve the additional purpose of a conventional underfill material. Post cure of the material may be needed.

[0005] Existing no-flow underfill materials have been shown to be unsatisfactory because of one or more reasons such as a very high CTE, high moisture absorption, etc.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The invention is further described by way of example with reference to the accompanying drawings wherein:

[0007] Figure 1 is a cross-sectional side view illustrating a partially assembled semiconductor package utilizing a no-flow underfill material;

[0008] Figure 2 is a view similar to Figure 1 after bumps formed on a die are located in the no-flow underfill material and in contact with bond pads on a substrate; and

[0009] Figure 3 is a view similar to Figure 2 after solder reflow.

## DETAILED DESCRIPTION OF THE INVENTION

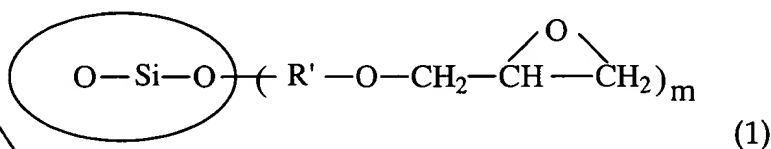
SUB A' >

[0010] A no-flow underfill material is provided that includes at least:

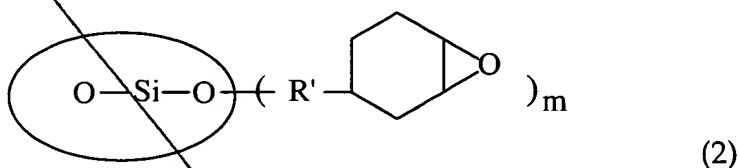
- (i) an epoxy siloxirane resin,
- (ii) at least one agent acting as a cross-linking hardener capable of curing an epoxy resin and a curing catalyst capable of catalyzing the curing of the epoxy resin, and
- (iii) a compatible fluxing agent.

SUB A2 >

[0011] The siloxirane resin may in its pre-cure monomer state be represented by:



or



where  $m$  is the number of reactive oxirane groups on the surface of the O-Si-O domain and  $m$  ranges from 1 to 30.  $\text{R}'$  is selected from the group consisting of phenylene, bisphenylene, carbonyl, and alkylene. The alkylene herein refers to a branched or unbranched saturated hydrocarbon group of 1 to 24 carbon atoms, such as methylene ("Me"), ethylene ("Et"), *n*-propylene, isopropylene, *n*-butylene, isobutylene, *t*-butylene, octylene, decylene, and the like. Preferred alkylene groups herein contain from 1 to 12

A2 carbon atoms. An organic moiety may be used in the monomer in eq. 1 to link the SiO<sub>2</sub> group with the oxirane group.

[0012] The SiO<sub>2</sub> group (O-Si-O) in eq. 1 or 2 can be a surface-grafted fused silica particle with a size less than 50 micron. Alternatively, the SiO<sub>2</sub> group can be a cyclic SiO<sub>2</sub> domain.

[0013] The SiO<sub>2</sub> group has a low CTE, low moisture uptake, and a high distortion temperature. A cyclic SiO<sub>2</sub> group also provides polymer flexibility and a correspondingly higher toughness.

[0014] The oxirane group CH<sub>2</sub>CHCH<sub>2</sub>O in eq. 1 is a diglycidyl ether type oxirane group and the oxirane group in eq. 2 is a cycloaliphatic oxirane group. The oxirane group in eq. 1 or eq. 2 provides cross-linking of the monomer with good adhesion to different surfaces. Cross-linking density of an eventual polymer can be controlled by the number of oxirane groups on each SiO<sub>2</sub> group.

SUB A3 [0015] The agent acting as a cross-linking hardener and a catalyst may be a single material such as an imidazole or its derivative, triphenylphosphine, or an onium salt. The agent may include a separate hardener and catalyst. The hardener may for example be an amine, an anhydride, a poly amide, a polyamide amine, or a phenolic resin and the catalyst may be an imidazolium salt, or a tertiary amine. The agent, during curing, creates a polymerized polymer out of the monomer with a three-dimensional cross-linked structure. The ratio at which the imidazole or its derivatives, or triphenylphosphine, or onium salt that is added in the formulation ranges from

0.01wt% to 20wt% of the weight of the siloxirane resin. The ratio at which amine, or polyamide, or polyamide amine that is added in the formulation is 1 reactive amine hydrogen equivalent to 0.1 to 10 epoxide equivalent of the siloxirane resin. The ratio at which anhydride that is added in the formulation is 1 anhydride ring equivalent to 0.1 to 10 epoxide equivalent weight of the siloxirane resin.

SUB A4  
[0016] The fluxing agent can be any acid which can be dissolved in the siloxirane resin and the agent. The fluxing agent is preferably an organic carboxylic acid, or a polymeric fluxing agent, or an organic compound that contains one or more hydroxyl groups. The fluxing agent may for example be a glutaric acid or a trifluoro acetic acid. The ratio at which a fluxing agent that is added in the formulation ranges from 0.1wt% to 20wt% of the weight of the siloxirane resin.

[0017] The material preferably further includes an adhesion promoter to further increase the adhesion strength between underfill material to all contact surfaces. The adhesion promoter may for example be a silane coupling agent, an organo-ziconate, or an organo-titanate. The ratio at which an adhesion promoter is added in the formulation ranges from 0.01wt% to 10wt% of the weight of the siloxirane resin.

SUB A5  
[0018] The material preferably further including a non-ionic surfactant to help material flow and eliminate process voids. The surfactant may be a polyol, a siloxane compound, and a fluorinated compound such as FC-430 from 3M Corporation of St. Paul, Minnesota. The ratio at which an adhesion promoter is added in the formulation ranges from 0.01wt% to 10wt% of the weight of the siloxirane resin.

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[0019] The material preferably further includes a de-foaming agent which prevents air entry and bubble formation during processing. The de-foaming agent may for example be BYK-066 from BYK-chemie of Wesel in Germany. The ratio at which a de-foaming agent is added in the formulation ranges from 0.01wt% to 10wt% of the weight of the siloxirane resin.

[0020] The material preferably further includes fused silica to further reduce CTE and moisture uptake, and increase modulus. The ratio at which a fused silica is added in the formulation ranges from 1wt% to 300wt% of the weight of the siloxirane resin.

[0021] The material preferably further includes silver flakes to provide electrical conductivity. The ratio at which a silver flake is added in the formulation ranges from 10wt% to 500wt% of the weight of the siloxirane resin.

[0022] The material preferably further includes thermally conductive particles to provide desired thermal conductivity. The thermally conductive particles may for example be silicon nitride, silicon borate, alumina, diamond, or silicon oxide. The ratio at which a thermally conductive particles is added in the formulation ranges from 10wt% to 500wt% of the weight of the siloxirane resin.

#### Example 1

- |    |  |                      |
|----|--|----------------------|
| a. | Siloxirane resin (eq. 1 or 2):                                   | 100 part (by weight) |
| b. | 2-ethyl-4-methyl imidazole acting as both hardener and catalyst: | 4 parts              |
| c. | Glutaric acid as a fluxing agent:                                | 4.0 part             |
| d. | FC-430 as a surfactant:  | 0.2 part             |
| e. | BYK-066 (defoaming agent):                                       | 0.05 part            |



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- f. 3-glycidoxy propyl methyl diisopropenoxy silane (adhesion promoter) 0.2 part
  - g. fused silica filler 40 parts

#### Example 2

- a. Siloxirane resin (eq. 1 or 2): 100 part (by weight)
- b. methyl hexahydrophthalic anhydride acting as a hardener: 100 parts
- c. triphenylphosphine acting as a catalyst: 0.8 parts
- d. Glutaric acid as a fluxing agent: 8.0 part
- e. glycerol (assisting fluxing agent) 8.0 parts
- f. polyoxyethylene (surfactant): 0.4 part
- g. BYK-066: 0.1 part
- h. neopentyl (diallyl)oxy tri(N-ethylenediamine) ethyl titanate (adhesion promoter) 0.6 part
- i. silicon nitride (thermally conductive particles) 100 parts

#### Example 3

- a. Siloxirane resin (eq. 1 or 2): 100 part (by weight)
- b. 2-phenyl-4,5-dihydroxymethylimidazole: 6 parts
- c. trifluoro acetic acid as a fluxing agent: 4.0 part
- d. silicone as a surfactant: 0.4 part
- e. BYK-066: 0.05 part
- f. neopentyl(diallyl)oxy tri(dioctyl) pyrophosphato zirconate (adhesion promoter) 0.3 part
- g. silver flakes (electrically conductive filler) 300 parts

[0023] Figures 1 to 3 illustrate how the no-flow underfill material is used in the construction of a semiconductor package. Figure 1 illustrates an initial stage in the assembly of the semiconductor package. The semiconductor package includes a package substrate 10, bond pads 12, a semiconductor die 14, contact pads 16, bumps 18, and the no-flow underfill material 20. The bond pads 12 are formed on an upper

surface of the package substrate 12. The contact pads 16 are formed on, as shown in Figure 1, a lower surface of the die 14 and the bumps 18 are formed on the contact pads 16 according to the well known controlled collapse chip connect (C4) process. The no-flow underfill material 20 is deposited over the upper surface of the substrate 10 and covers all previously exposed surfaces of the bond pads 12.

[0024] As shown in Figure 2, the bumps 18 are then inserted into the no-flow underfill material 20 until each bump 18 contacts a respective bond pad 12. The no-flow underfill material 20 then fills regions between the bumps 18.

[0025] The assembly of Figure 2 is then passed through a reflow oven or thermal compressive bonder to form a final assembly as shown in Figure 3 of a semiconductor package 22 according to an embodiment of the invention. The bumps 18 reflow at a temperature higher than their melting point so that they reflow over the bond pads 12. The material 20 serves to remove oxygen from the bumps 18 and the bond pads 12. The removal of oxygen facilitates the formation of a more reliable electrical joint between each bump 18 and its respective bond pad 12.

[0026] The temperature to which the assembly in Figure 2 is cycled is also sufficiently high to cause cross-linking of oxirane groups to form a very strong polymer. The material 20 thus solidifies, as is required for purposes of distributing stresses which tend to shear the bumps 18 from the bond pads 12 and the contact pads 16.

[0027] While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely

illustrative and not restrictive of the current invention, and that this invention is not restricted to the specific constructions and arrangements shown and described since modifications may occur to those ordinarily skilled in the art.

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